

Causes and Effects of Uncontrolled Water Inrush into a Decommissioned Mine Shaft

Krzysztof Polak¹ · Kazimierz Rózkowski¹ · Piotr Czaja¹

Received: 14 November 2014 / Accepted: 21 July 2015 / Published online: 31 July 2015
© The Author(s) 2015. This article is published with open access at Springerlink.com

Abstract Central Europe experienced catastrophic rain-falls and flooding in 2010. This paper discusses a decommissioned shaft that was flooded by surface water, which led to displacement of shaft backfill and an inrush of large amounts of water into an underground pumping station. The weather conditions for the period preceding the inrush, the hydrogeological conditions, the quantity of water that entered the mine dewatering systems, and the underground hydraulic connections are all described. Uncontrolled inflow of water as a cause of backfill saturation and the hazard for active underground infrastructure were analysed. A need to rebuild damaged infrastructure was identified. The case study highlights the need to improve underground mine closure requirements to ensure safe conditions above ground, particularly in densely populated areas.

Keywords Groundwater hazard · Backfill saturation · Mine flooding

Introduction

The Upper Silesian Coal Basin (USCB) has a long history of intensive coal mining, which has created a network of interconnected and abandoned workings, some of which are connected with neighbouring mining areas (Rózkowski and Rózkowski 2011). Since 1989, the mining industry in Poland has undergone large-scale restructuring due to coal deposit depletion and the changed economic environment. In some cases, production stopped gradually. Adjacent operations with uneven potential were combined to form stronger entities with lower production costs. Due to the close proximity of many mines and the multi-level operations, numerous connections remain between the mines, directly through underground workings or through safety pillars of variable thickness that separate adjacent abandoned workings.

Complete cessation of operations and physical decommissioning of the mine workings was possible only in isolated areas. As unprofitable operations or areas with depleted resources were closed, it became necessary to protect nearby active operations that still had economically recoverable reserves (Bradecki and Dubiński 2005). Therefore, it was often essential to maintain drainage, often at a higher elevation, at discontinued operations.

The complicated geological and mining landscape requires a vast drainage system, creating a regional cone of depression. In the process of liquidation and restructuring of the coal mines, it became necessary to reconstruct and modify the existing individual drainage systems. The lowest levels of the interconnections were considered, existing safety pillars were verified, and watertight barricades were planned and built. Bukowski (2002) drew attention to the need to consider the water storage capacity of the rock mass, as modified by coal exploitation, in the calculations. The reorganisation redirected some of the water inflow into the

✉ Krzysztof Polak
kpolak@agh.edu.pl

Kazimierz Rózkowski
kazik@agh.edu.pl

Piotr Czaja
czajap@agh.edu.pl

¹ Faculty of Mining and Geoengineering, AGH University of Science and Technology, Al. Mickiewicza 30, 30059 Cracow, Poland

remaining main drainage systems, and in many cases, the yield and reserves were increased in preparation for the raised water level. Under favourable conditions, stationary systems in the decommissioned mines were replaced with deep-water drainage. This reduced costs, while increasing safety and retention capacity in the case of an uncontrolled, rapid inflow (Bukowski 2011; Frolik and Kubica 2005).

Drainage carried out in the Siemianowice area, including the former Siemianowice and Barbara Chorzów mines, was seriously threatened in 2010, when an uncontrolled inrush of water took place. An investigation to identify the source of the inflow was immediately undertaken with a view to long-term decommissioning.

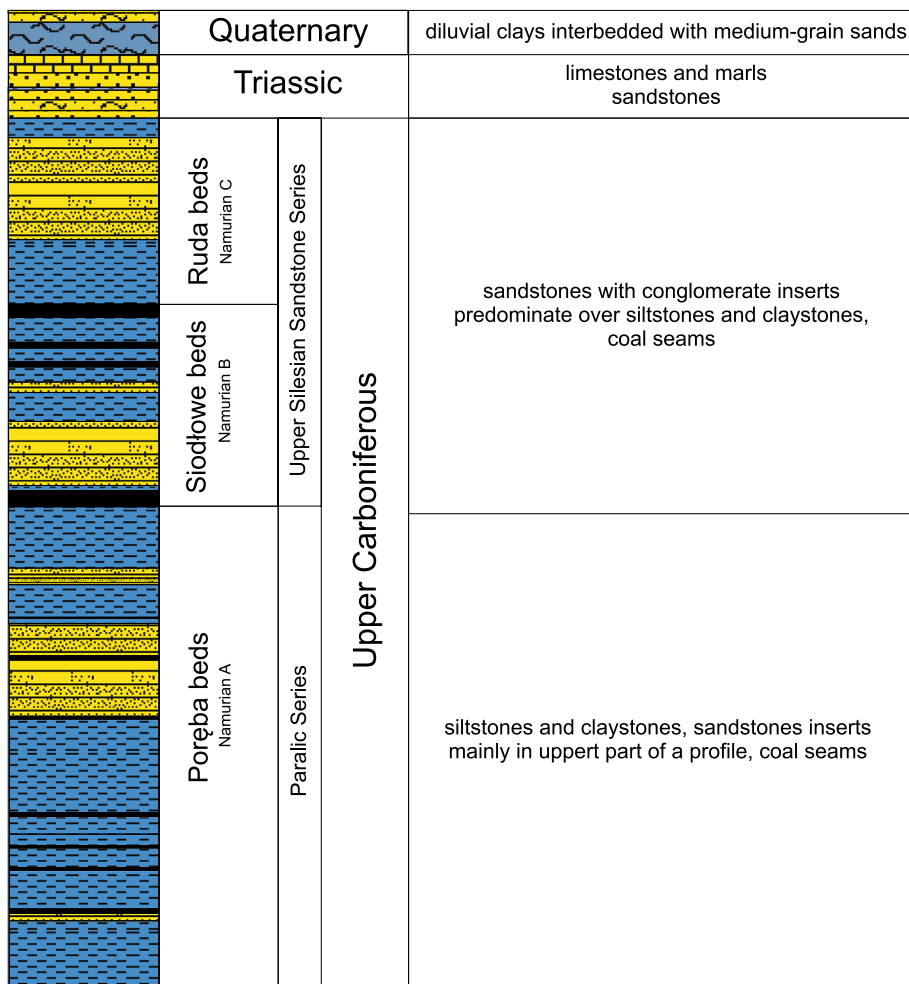
Outline of the Geological Structure and Hydrogeological Conditions

The area of water inrush was located within a local structural trough, with its axis aligned in a NW–SE direction. Slightly to the south of the basin’s axis is the Park shaft. In this part of the structure, the overburden is mainly Quaternary strata

deposited as interbedded medium-grain sands and diluvial clays that range in thickness from a few metres to about 20 m, and locally thin Triassic deposits. Further underground, there are Carboniferous Ruda and Siodłowe beds of the Upper Silesian sandstone series (GSP), in which the coal is found. This series is dominated by sandstones, with conglomerate over siltstone and claystone strata. The aquifers within the GSP complex are linked by thick sandstones shoals, ranging from 0.2 to 44.5 m in thickness (Kotas 1994; Fig. 1). The permeability of the water-bearing beds decreases with depth, ranging from 2.5×10^{-5} to 4.0×10^{-11} m/s. Effective porosity also decreases with depth, from 20.9 % to just 0.1 % (Rogoż et al. 1987; Rózkowski 2000, 2004).

North from the axis of the trough, the overburden contains sands of variable grain size up to 20 m thick. These sands fill a subordinate, local erosion trough. The Muschelkalk limestone (Middle Triassic) strata, composed of limestones, marls, and limestone marls, are deposited at the base of the Quaternary, sometimes with crystalline limestone debris or gray crystalline limestone rubble, with a maximum thickness of 80.0 m. The Triassic sediments lay directly on the Ruda beds.

Fig. 1 Hydrogeological profile of Park shaft



The Water Hazard

Before 2010, there had been six inrushes of water into shaft mine workings in the USCB. Water hazard assessment in active shafts in USCB mines has been described by Bukowski (2011). The event which became the basis of the analysis described herein had two stages. On 2 Oct 2010, a rapid, uncontrolled inrush of large volumes of water took place, most likely to drainage gallery no. 1 of the main pumping station in the Siemianowice III shaft, at the 321 m level. Emergency procedures caused automatic deactivation of the pumps. Water flooded the main pumping station and the adjacent workings, up to about 0.5 km in the direction of the Bańgów shaft, to a height of up to 1.4 m. The drainage system equipment was damaged or destroyed. The rushing water left behind ferruginous sediments, and fine shale, coal shale with coal, and even slag. During the site visit conducted during emergency actions, a complete loss of flow was discovered behind a barricade in the cross-cut connecting SI–SII from colliery II (Ficinus) of the former Siemianowice Mine. The remaining three barricades in this region were functioning as usual, allowing the free flow of suspended matter at a rate of several litres per minute, similar to before.

The additional inflow to the pumping station within 7 h of the inrush was estimated at about 7000–8500 m³. In the first hour, the inflow rate reached 33.0 m³/min, then dropped by 1/3 during the next 6 h, to about 21.0 m³/min. Emergency protective actions allowed the ventilation necessary to conduct further drainage through the adjacent Bańgów shaft to be maintained.

After just 7 days, another uncontrolled inrush of water area took place. Outflow from behind the barricades gradually increased, reaching an estimated maximum of 30.0 m³/min. Inflow into the main cross-cut at the 321 m level occurred simultaneously with the failure of barricades near the Park shaft, which had been decommissioned several years earlier. The pumping station in the adjacent shaft base was flooded. The flooding of 2 km of the 321 m level cross-cut prevented the ventilation system from properly functioning. For another 4 days, the water level continued to rise, until it broke through the main 321 m level cross-cut into the nearby Bańgów pumping station. From then on, the pumping station received almost double the normal inflow of water, and was operated in emergency mode.

The Meteorological and Hydrogeological Situation

The search for the causes of this unexpected and dangerous event began immediately after the first inrush. It was necessary to analyse the hydrogeological and mining conditions, mainly the spatial structure of the mine workings,

particularly the direct and indirect connections of neighbouring mines to the surface, the inflows to adjacent pumping stations, and finally the spatial and temporal rainfall structure. Annual discharges pumped from abandoned mines from 1997 to 2007 in the USCB were compared with annual rainfall data by Janson et al. (2009). The distribution and intensity of rainfall in Poland and Central Europe in 2010 was very unusual, and caused a series of major floods. The nearby Institute of Meteorology and Water Management (IMGW) station at Czeladź recorded 1038 mm of rainfall in 2010; the average rainfall in this region is \approx 650–700 mm. The monthly distribution of rainfall was also highly unusual, with a maximum in May (Fig. 2).

Rainfall during May 2010 totalled 267 mm, exceeding the mean value by several times. Torrential rainstorms generated greater surface runoff than many drainage systems could handle. Surface flooding occurred in many places, including the area where the analysed inrush of water into the mine workings took place 5 months later. The area affected by the flooding, dictated by the morphology of the area, was in Zwycięstwa Street in Siemianowice Śląskie, northwest of the Park shaft. The flood covered an undeveloped area, mainly used for agricultural purposes, with an area of 3.136 ha. The volume of accumulated water was estimated at 47,000 m³. After a reservoir was created, the ditch and the culvert at Zwycięstwa Street was cleaned, and drainage was directed towards Rzęsa Pond. In September 2010, 108 mm of rainfall was recorded, mostly in the last days of the month. The average September rainfall from 1991 to 2010 for the IMGW station at Czeladź is 66 mm.

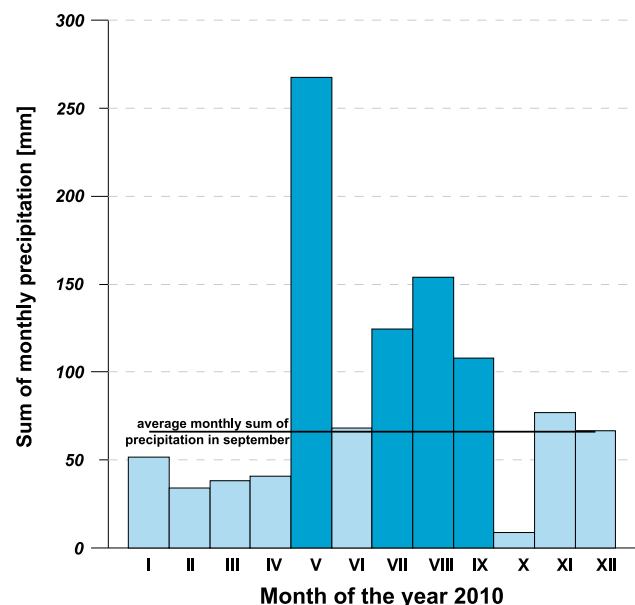


Fig. 2 Monthly precipitation at the IMGW Czeladź station in 2010

Water Flow into the Drainage System

Heavy rainfall in 2010 increased water inflow into the drainage systems of both active and inactive mines. All pumping stations operated by the Central Department of Mine Drainage (Centralny Zakład Odwadniania Kopalń, CZOK) in the Siemianowice area recorded increased groundwater inflow from May 2010. In the Siemianowice drainage area, there are two stationary drainage systems to maintain 13,250 m of mine tunnels and 4 shafts to a maximum depth of 1964 m:

- the Siemianowice system includes the Siemianowice III and Bańgów shafts and two pumping stations at the 321 m level, and;
- the Chorzów system includes the Kolejowy I and Zygmunt-August II shafts and the main drainage pumping stations at levels 321 and 630 m.

These two systems previously served the Siemianowice and Barbara Chorzów mines, which are now connected by a water gallery at the 630 m level, where the water flows by gravity from the abandoned workings of the Siemianowice Mine to the stationary pumping station at the Kolejowy I shaft. The overflow elevation between these mines is at 327.0 m above sea level (ASL).

The Siemianowice drainage area is defined by historical mines with relatively shallow seams. It receives water predominantly from the drainage basin and hydraulic connections. The volume of free water accumulated in the pore space was practically depleted. Such inflows are, by definition, dependent on rainfall infiltration into the rock mass. Inflow time is variable and depends on the path through which the water migrates.

The high May 2010 rainfall intensified inflows into the Siemianowice and Chorzów drainage systems by nearly 20 %. From May to September 2010, the Siemianowice pumping station pumped 600,000 m³ of water more than average. Variation in the mean monthly inflows reached 34 % in the case of the Siemianowice system, and 28 % within the Chorzów system. In both cases, the largest inflows were recorded in September 2010, and the smallest occurred in March and April 2010. The summary of inflows to the individual pumping stations of the Siemianowice and Chorzów systems is shown in Fig. 3.

The average water supply to the Siemianowice area for 2010 reached 16.4 and 14.9 m³/min at the Chorzów pumping station. In the final stage of mining, between 1989 and 1998, the total inflow into the Siemianowice coal mine ranged from 19.8 to 28.5 m³/min, classifying the mine as one of the wettest in the Bytom basin (Proberz and Zajac 2000).

An analysis of the results presented in Fig. 2 shows considerable differences. During 2010, the amount of water pumped by the Kolejowy I shaft pumping station at the

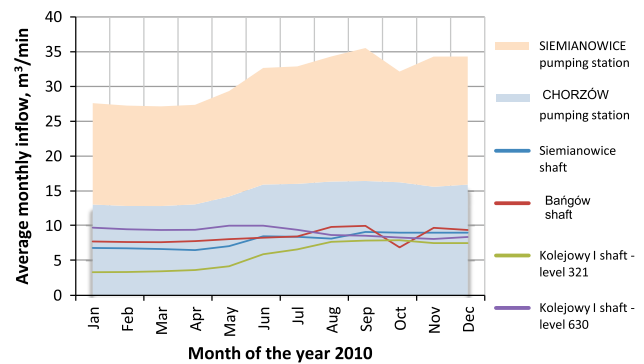


Fig. 3 Inflows to the individual pumping stations in the Siemianowice drainage area (CZOK)

630 m level decreased by about 10 %. This level is much deeper than the three others interacting in this system, and most likely does not have a direct hydraulic connection with the surface. These three other pumping stations, built at the 321 m level, showed substantially increased inflows. The amount of water discharged from the Bańgów pumping station during October 2010 may have been underestimated due to the emergency operations and changes to the layout of the drainage system. The data (Fig. 2) also indicate that inflows to the individual pumping stations depended on the amount of rainfall, which indicates a connection between the pumping stations and the surface.

Reasons for Water Inrush into the Siemianowice III Pumping Station

The likely scenarios of events were reconstructed by analysing the water supply and drainage conditions, the geological data and mining practices, observations made during the site visits, and eye-witness accounts. Consideration was given to, among others, the Team of Advisors of the Director of CZOK, the Consultative Team Committee for Water Hazard Recognition and Control at SRK SA, and the State Mining Authority Committee for Water Hazards. In the course of investigating the causes of the flooding of the Siemianowice III pumping station, it was discovered that the sequence of events began with the displacement of backfill in the Park shaft. The shaft is indirectly connected to the surface by a mining excavation.

Decommissioning of the Park Shaft

A total of 345 Polish coal mine shafts were decommissioned from 1970 to 2010 (Czaja 2011). Major events during decommissioning, including the explosion of methane in the decommissioned Morcinek mine shaft in 1994 and the blockage of the backfill above the base of the

Jadwiga shaft in the Porąbka Klimontów Mine in 2000, caused a very careful analysis of all the shaft decommissioning projects. Most shafts had been decommissioned in the last few years of the twentieth century, and the guidelines and design requirements were also developed at that time.

In a shaft filled with granular material, the weight of the material causes vertical and horizontal pressures. The horizontal pressure causes friction against the shaft lining, the magnitude of which depends on the coefficient of friction (dependent on the type of backfill) and the lateral earth pressure. With increased depth, both the horizontal and vertical pressures increase, but stabilise at a depth, based on theoretical calculations and practical experience, approximately equal to eight times the diameter of the shaft (Czaja 2011). The dry backfill pressure in the shaft can be determined from Janssen's formula (Durn 1982):

$$p_x = \frac{\gamma F}{fU} \left(1 - e^{-\frac{f}{k}H}\right)$$

where γ = the bulk density of the rock material, F = the cross-sectional area of the shaft, U = the circumference of the shaft, H = the depth of the backfill, f = the friction coefficient against the lining of the shaft, and k = the ratio of vertical to horizontal pressure, according to the formula:

$$k = \frac{1}{\lambda}$$

where λ = the horizontal spreading coefficient defined according to the relationship:

$$\lambda = \tan^2 \left(45 - \frac{\phi}{2}\right)$$

ϕ = the angle of internal friction.

The pressure tends asymptotically to the value of p_{max} , according to the formula:

$$p_{max} = \frac{\lambda R}{f}$$

where R = hydraulic radius.

A large frictional force from dry backfill against the lining does not exert too much pressure on the lining, even in deep shafts. Over time, water infiltrates the backfill. The presence of water reduces the frictional force of the backfill material against the shaft's lining, but the accumulated water in the shaft adds additional pressure, as described by:

$$P = h_w \gamma_w$$

where h_w = the hydraulic head and γ_w = the specific gravity of the aqueous solution in the shaft.

The difference in hydrostatic pressure between the backfill and the 'dry' tunnels located below was so great that sliding of the backfill is practically inevitable, which

led to the sudden failure of the soaked backfill into the mine workings. The backfill movement increased the dynamic pressure, which in turn caused the backfill to move into the horizontal workings in the shaft base. This sudden release of support to the internal lining of the shaft, especially above the backfill, led to the destruction of the lining and 'collapse' of the shaft.

The sudden subsidence of the backfill created negative pressure, which sucked air into the interior of the shaft in an amount equal to the void volume created above the backfill. Since the top of the shaft is covered with a cap, the negative pressure unclogged the least resistant hydraulic connections. This may have caused sinkholes to form, shallow excavations to collapse, induced the formation of voids and discontinuous deformations, and the devastation of underground infrastructure and installations, including sewage and drainage systems.

In designing shaft decommissioning, the first priority should be to solve this fluidisation problem. For this purpose, different types of retaining structures are built in the shaft base to prevent backfill from creeping into horizontal galleries. A barricade must therefore be able to withstand a pressure equal to the hydrostatic pressure of the water and rock column with a height corresponding to the distance between the shaft collar and the barricade. In the case of a 200 m deep shaft, a pressure of 2.0 MPa should be assumed. Therefore, it is necessary to build the barricade a few metres thick, using materials that provide the required strength (Czaja 2011). The equilibrium horizontal pressure at the barricade is:

$$P_x = sh p_x = T_1 + 2T_2$$

where s = the width of the horizontal gallery, h = the height of the horizontal gallery, p_x = the horizontal pressure acting on the dam, T_1 = the friction against the floor of the horizontal gallery, and T_2 = the friction against the side walls of the horizontal gallery. The static frictional force of the backfill against the side walls and the floor of the gallery can be calculated from the formulae:

$$T_1 = \frac{\gamma shlf}{2}$$

and

$$T_2 = \frac{\gamma h^2 \lambda lf}{2}$$

The formula used to calculate the length of the base of the slope to stabilize the backfill in the inlet to the shaft is:

$$l = \frac{2s\lambda(P + \gamma h)}{\gamma f(2s + h\lambda)}$$

which shows that the saturation of the backfill changes the equilibrium conditions of the barricade in two ways: First,

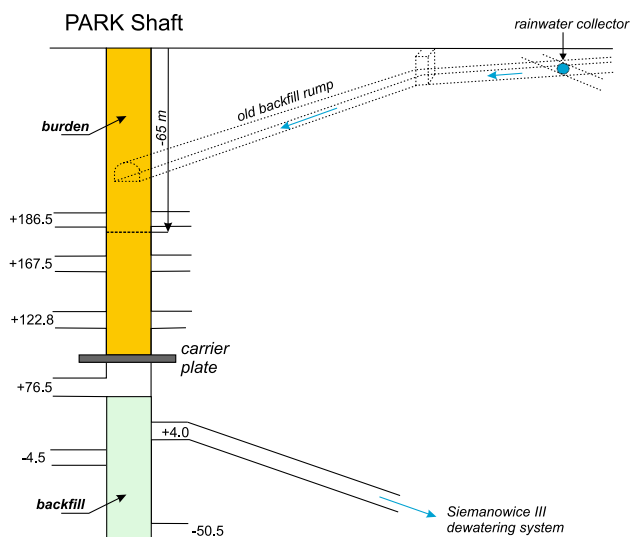


Fig. 4 Diagram of the decommissioned and existing connections in the Park shaft, with the shallow subsurface galleries

soaking of the backfill reduces its friction coefficient, f , and second, the accumulation of water in the shaft increases the weight of the backfill and the vertical pressure, P .

Causes of Backfill Slippage in the Park Shaft

The Park shaft was decommissioned in two stages by building a reinforced concrete support plate about 127 m above the base of the shaft, i.e. at the 206 level. The backfilling was performed separately for each of the individual parts over a few years, starting in the upper part of the shaft. A schematic diagram of the decommissioning and shaft connections is shown in Fig. 4.

After the Siemianowice III shaft pumping station flooded, subsidence of the backfill occurred about 65 m below the ground surface. Displacement of the backfill might have taken place throughout the entire shaft depth, not just

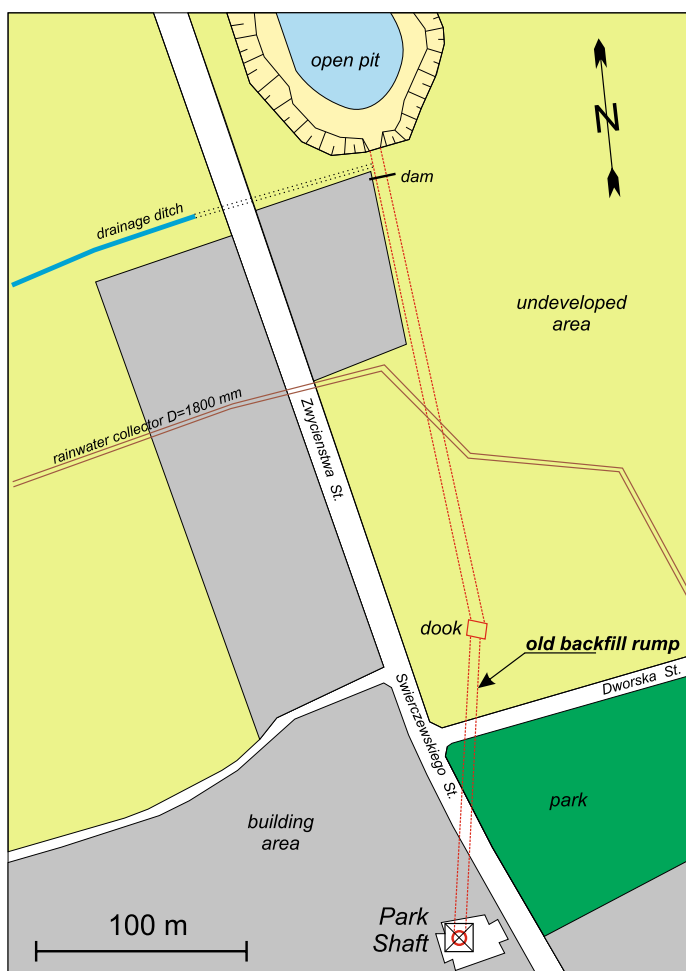


Fig. 5 Schematic sketch of the Park shaft position, showing both old mine workings and modern infrastructure

in the upper segment. This may have been due to destruction of the:

- carrier plate and slippage of the backfill below the plate's original level, or
- barricades built in the galleries above the carrier plate and displacement of the backfill into these workings.

The first of these possibilities seems more likely, based on the disappearance of water flow from the cross-cut connecting Siemianowice I–Siemianowice II, as was observed after the first inrush of water into the Siemianowice III shaft pumping station. Assuming that the lower part of the Park shaft was decommissioned in accordance with the operations plan, damage to the reinforced concrete plate would have caused the backfill to move into the base of the shaft. Next, with the water, the backfill material (which included slag, ferruginous sediments, fine silt shale, and coal shale) was transported into the cross-cut connecting Siemianowice I–Siemianowice II and, finally, towards the pumping station at the Siemianowice III shaft. This backfill appeared with the first inrush of waters on 2 Oct 2010.

Lack of drainage through the SI–SII cross-cut flowing from the Ficus colliery, as well as water flowing through the connection with the surface, caused further damming of water in the mine workings, particularly in the old workings of seams 615 and 620, which led to overflow through the galleries in the vicinity of the Park shaft and through the barricades protecting the shaft, to the Siemianowice III pumping station on 9 Oct 2010.

Analysis of the meteorological data and events resulting in the flooding of the pumping station at the Siemianowice III shaft indicates that the cause of backfill slippage might have been a sudden uncontrolled flow of rainwater from the surface to the decommissioned shaft. Analysis of the hydraulic connections between the Park shaft and the mine workings indicate that the shaft was connected to the backfill by a cross-cut and to the shallow mining galleries that had been used for delivering the backfill (Fig. 5).

Analysis of archival materials made available by the Siemianowice City Council also points to a connection between the shallow underground workings and the storm water collector. This hypothesis was confirmed during a site visit by the authors.

Conclusions and Final Remarks

Analysis of the documented material leads to the conclusion that a sudden inflow of water from near the Park shaft caused the flooding of Siemianowice III shaft the pumping station. This inrush was caused by the release of water

stored in the shaft backfill. The amount of water stored in the shaft had increased over the previous few months, due to infiltration of the intense rainfalls that occurred in May and at the end of September 2010.

As the shaft backfill became saturated, the backfill material began to slip, reducing the hydraulic pressure on the reinforced concrete plate, and causing it to slip. Consequently, the plate was damaged and the saturated backfill entered the shaft base, followed by sudden displacement of the backfill into the underlying galleries. The movement of the backfill resulted in approximately 70,000 m³ flowing towards the stationary Siemianowice III shaft pumping station. Furthermore, the abrupt slippage of the backfill would have induced negative pressure on the shaft collar, unclogging hydraulic connections with the subsurface infrastructure, and probably damaging the rainwater collector, though it is also possible that this damage might have occurred before the backfill slipped. In the latter case, the damaged rainwater collector could have been the direct cause of excessive amounts of rainwater entering into the Park shaft.

A concurrent, almost immediate increase in the inflow to the Bańgów pumping station, which plays a vital drainage role in the Siemianowice region, was observed following the increase in rainfall. This is evidence for the unclogging of hydraulic connections, a process that is partly responsible for CZOK's cost increase.

The slippage of backfill into the Park shaft resulted in a lack of support for the upper section of the shaft at a depth 65 m from the surface. Because the shaft is located in the city and the surroundings of the shaft are heavily urbanised, it was necessary to immediately protect the shaft by supporting the void with backfill. In order to prevent repeated water inflow into the backfill, it is also necessary to rebuild the destroyed subsurface infrastructure, including the intersection of the damaged transport excavation with the rainwater collector.

Open Access This article is distributed under the terms of the Creative Commons Attribution 4.0 International License (<http://creativecommons.org/licenses/by/4.0/>), which permits unrestricted use, distribution, and reproduction in any medium, provided you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license, and indicate if changes were made.

References

- Bradecki W, Dubiński J (2005) Effect of the restructuring of the Polish coal-mining industry on the level of natural hazards. *Arch Min Sci* 50(1):49–67
- Bukowski P (2002) The water storage capacity of a carboniferous rock mass and its impact on the flooding process of mine workings in the Upper Silesian Coal Basin. *Arch Min Sci* 47(3):385–412

- Bukowski P (2011) Water hazard assessment in active shafts in Upper Silesian Coal Basin Mines. *Mine Water Environ* 30:302–311. doi:[10.1007/s10230-011-0148-2](https://doi.org/10.1007/s10230-011-0148-2)
- Czaja P (2011) The technology of mineshaft decommissioning with associated underground and surface infrastructure. Wydawnictwa AGH, Kraków **(in Polish)**
- Durn RB (1982) The treatment of disused mine shafts and adits. Mining Dept, National Coal Board, London
- Frolik A, Kubica J (2005) Evaluation of the water hazard condition and its risk in hard coal mines. *Prace naukowe GIG, Górnictwo i środowisko* 4(2005):61–76 **(in Polish)**
- Janson E, Gzyl G, Banks D (2009) The occurrence and quality of mine water in the Upper Silesian Coal Basin, Poland. *Mine Water Environ* 28:232–244. doi:[10.1007/s10230-009-0079-3](https://doi.org/10.1007/s10230-009-0079-3)
- Kotas A (1994) Coal-bed methane potential of the Upper Silesian Coal Basin, Poland. Państwowy Instytut Geologiczny, Warszawa
- Probierz K, Zajac A (2000) Analyses of hydrogeological conditions changes in decommissioned Siemianowice mining plant Ltd Co and Rozalia mining plant. *Wiadomości Górnicze* 6(2000):283–288 **(in Polish)**
- Rogoż M, Rózkowski A, Wilk Z (1987) Hydrogeological problems in the Upper Silesian Coal Basin. In: Proceedings of international symposium on the hydrogeology of a Coal Basin, IMWA, Katowice, Poland, pp 553–566
- Rózkowski A (2000) Coal mine water chemistry (Upper Silesian Coal Basin, Poland). In: Proceedings of 7th international mine water association Congress, Ustroń, pp 634–644
- Rózkowski A (2004) Hydrogeochemical environment of Carboniferous coalbearing formations of the Upper Silesian Coal Basin. *Prace Naukowe Uniwersytetu Śląskiego w Katowicach*, nr 2244. Wydawnictwo Uniwersytetu Śląskiego, Katowice **(in Polish)**
- Rózkowski A, Rózkowski K (2011) Impact of coal mining activity on ground and surface waters environment in the Upper Silesian coal basin in the multiyear period. *Biuletyn PIG, Hydrogeologia* 445:583–592 **(in Polish)**